A Helicoidal–Solitonic Field Model of Fundamental Particles and Emergent Space and Time

Author: Heitor Chierentin
Affiliation: Independent Researcher
Year: 2026

Abstract

We propose an alternative field-theoretic description of fundamental particles, modeling them not as point-like objects or one-dimensional strings, but as self-confined helicoidal field structures organized as concentric vortical configurations. These entities behave as dissipative topological solitons, whose particle identity is preserved by conserved winding and linking invariants despite continuous energy dissipation.

The internal dynamics of each structure is characterized by a self-referential helicoidal oscillation associated with progressive internal energy densification and topological compression of the vortex core. Intrinsic phase slippage and dynamic hysteresis arise naturally in this process, leading to irreversible energy redistribution into the surrounding field while maintaining global structural stability.

When a population of such solitons approaches phase synchronization, the global field may undergo collective instabilities, allowing new solitonic structures to emerge as stable, coherent solutions. Particle creation is therefore interpreted as a nonlocal, resonant reconfiguration of the field rather than as a strictly local interaction.

In three spatial dimensions, a material particle may be represented as the dynamic intersection of three mutually orthogonal helicoidal vortices, forming a stable topological knot in which convergent helicoidal flows define a common topological center. Matter is thus interpreted as a self-convergent mode of field dynamics rather than as a static localized object.

We further suggest that the progressive topological contraction of solitonic cores implies an effective increase in the average separation between vortex centers, leading to the emergence of space as a geometric consequence of relational distancing rather than intrinsic field expansion. Interactions between solitons are modeled as phase couplings within the helicoidal field, allowing effective attractive behavior to arise as a collective, statistical consequence of dissipative dynamics.

Within this framework, temporal directionality is interpreted as an emergent ordering parameter associated with cumulative dissipation, rather than as a fundamental external coordinate.

Although primarily conceptual and phenomenological, the proposed model offers a unified perspective on particle identity, irreversibility, and the emergence of space and time, and may serve as a foundation for further mathematical development in dissipative and topological field theories.

1. Introduction

Contemporary high-energy physics describes elementary particles either as point-like excitations of quantum fields or, in extended frameworks, as one-dimensional strings. While such models have achieved remarkable predictive success, they leave open foundational

questions concerning particle identity, long-term stability, irreversibility, and the physical origin of space itself.

In standard formulations, particles are treated as localized excitations whose persistence is largely postulated rather than dynamically derived. Dissipation, hysteresis, and irreversible processes are typically introduced phenomenologically or relegated to effective descriptions, despite their central role in nonlinear field systems across condensed matter physics, fluid dynamics, and plasma physics.

Motivated by these considerations, we explore an alternative description in which particles are modeled as topologically stabilized field configurations. Specifically, we propose that fundamental particles correspond to self-confined helicoidal vortices of a continuous field, organized as concentric spiral structures. These configurations behave as dissipative topological solitons. Although they continuously exchange energy with the surrounding field, their global topological identity remains preserved.

Within this framework, the internal dynamics of a particle is governed by a self-referential helicoidal oscillation. This motion induces a gradual densification of energy toward the vortex core, accompanied by progressive topological compression. Crucially, the oscillation is not perfectly reversible. Intrinsic phase slippage introduces dynamic hysteresis, resulting in irreversible energy dissipation into the ambient field.

When many such helicoidal solitons coexist within a shared field and their internal oscillations approach phase synchronization, the system may enter a regime of collective instability. Under these conditions, new solitons can emerge as coherent and stable solutions of the global field configuration. Particle creation, in this view, is therefore understood not as a strictly local process but as a resonant, system-wide reorganization mediated by collective dynamics.

Furthermore, the continuous topological contraction of solitonic cores implies an effective increase in the average separation between vortex centers. Space is thus interpreted as an emergent geometric effect arising from relational distancing between material structures, rather than from intrinsic expansion of the underlying field itself.

This model, here designated as the Helicoidal–Solitonic Field Model, can also be succinctly expressed in a conceptual and popular form as Spiral Theory.

The present work is not intended as a replacement for quantum field theory or the Standard Model of particles. Rather, it offers a conceptual and phenomenological framework aimed at exploring how particle identity, irreversibility, and spacetime structure may emerge from dissipative and topological field dynamics. It should be understood as an effective, coarse-grained, pre-quantum, or even sub-quantum, description, from which standard Quantum Field Theory behavior may emerge statistically in appropriate regimes.

Although conceptually reminiscent of extended-object approaches, the helicoidal–solitonic model does not rely on string-like fundamental entities or extra spatial dimensions. Instead, it generates three-dimensional space and particle properties mainly from intrinsic topological configurations of a continuous field.

2. Field Definition, Physical Interpretation and Dynamical Framework

In the present framework, dissipation is not interpreted as energy loss to an external environment, but as an intrinsic topological property of self-referential helicoidal field configurations. Energy is redistributed

into delocalized field modes while topological invariants remain conserved. Unitary evolution thus appears as an effective approximation valid in regimes where helicoidal phase slippage is negligible.

2.1 Fundamental Structure

We propose that fundamental particles behave as dissipative topological solitons, in which the particle’s identity is preserved despite gradual energy losses. The stabilized field configurations are characterized by persistent phase winding and topological invariants.

Here, we model the fundamental substrate of physical reality as a continuous complex vector field.

The particle is understood as a stable field configuration, sustained by nonlinearities and topological constraints, rather than as a rigid material object.

Locally, the field dynamics may be decomposed into radial, azimuthal, and longitudinal components. A single solitonic particle is thus described as a vortex tube whose internal phase advances helicoidally along its axis, producing a persistent circulation coupled to axial oscillation.

The concentric nature of the helicoidal structure implies an internal gradient of phase velocity and energy density. Inner layers are dynamically compressed, while outer layers interact more strongly with the surrounding field, allowing controlled dissipation.

This works employs three distinct evolution parameters with contemplementary roles. The symbol τ denotes a purely local descriptive parameter used to label internal field dynamics, without physical temporal meaning. The Variable T representes an emergente, strictly monotonic ordering parameter defined by cumulative dissipation, encoding irreversibility and an intrinsic arrow or time.

Finally, Θ denotes a global phase ordering parameter associated with collective synchronization and long-range coherence. In this work, neither T nor Θ correspond to spacetime time. Instead, they act as internal organizational parameters governing irreversible evolution and global phase regulation.

2.2 Effective Dynamical Equation

At the present stage, the following equation is introduced as an effective phenomenological model, intended to capture the large-scale dynamics of helicoidal solitonic configurations, rather than as a fundamental microscopic law.

Helicoidal solitonic solutions of this class of equations naturally exhibit phase slippage, internal hysteresis, and long-lived topological stability under dissipation, consistent with the qualitative behavior described in this work.

As a minimal dynamical model consistent with the proposed framework, we introduce an effective nonlinear field equation. The Complex Ginzburg–Landau Equation (CGLE) is a nonlinear partial differential equation describing the evolution of a complex order parameter near a Hopf bifurcation in dissipative systems.

Its general form is:

$$\partial \Psi / \partial T = \Psi + (1 + i\alpha) \nabla^2 \Psi - (1 + i\beta) \vee \Psi \vee^2 \Psi$$

where:

Ψ (x, T) is a complex order parameter (field amplitude);

T is an emergent irreversible evolution parameter;

∇^2 is a Laplacian operator (spatial diffusion);

α is a linear dispersion coefficient;

β is a nonlinear dispersion coefficient;

i is an imaginary unit ($i^2 = -1$);

$|\Psi|^2 = \Psi \cdot \Psi^*$ is the squared modulus of the field.

Here in (x, T), x labels effective relational degrees of freedom, while T is an emergent monotonic parameter encoding irreversible dissipative evolution, rather than a physical spacetime time coordinate.

Besides that, its expanded Laplacian (3D Cartesian coordinates) form is:

$$\nabla^2 \Psi = \partial^2 \Psi / \partial x^2 + \partial^2 \Psi / \partial y^2 + \partial^2 \Psi / \partial z^2$$

Also, an alternative dimensional form is:

$$\partial \Psi / \partial T = \varepsilon \Psi + (D_1 + i\, D_2) \nabla^2 \Psi - (g_1 + i\, g_2) |\Psi|^2 \Psi$$

where ε, D_1, D_2, g_1, g_2 are real coefficients controlling growth, diffusion, and nonlinear amplitude saturation.

Here, instead of the conventional amplitude A, the complex order parameter is denoted by $\Psi(x, T)$, representing the local helicoidal excitation amplitude and phase.

In this work, this equation is interpreted as describing a fundamental helicoidal field whose stable non-trivial solutions correspond to particle-like solitons. Nonlinear saturation limits the growth of the helicoidal excitation, fixing a finite amplitude and internal scale.

The CGLE is not assumed to be fundamental, but rather the universal normal form governing the slow dynamics of the helicoidal field near a stability threshold. Also, no claim is made that it represents a fundamental relativistic field equation.

As we will consider widely in section 7, CGLE here governs irreversible evolution along T, while phase coherence and long-range synchronization are regulated independently along the Θ-axis.

Importantly, within this model Ψ does not correspond to wave-function. The field Ψ is treated throughout as a classical, coarse-

grained order parameter, not as an operator-valued quantum field. Quantization, if applicable, would occur only at an emergent collective level.

2.3 Field Definition

The fundamental field can be represented as a complex helicoidal field, defined in cylindrical coordinates (r, θ, z), of the form

$$\Psi¿\tau \mid T, \Theta)¿ A(r)\exp ¿\tau + kz+n\theta ¿¿$$

where:

Ψ(r, θ, z; τ | T, Θ) is the complex helicoidal fundamental field;

A(r) is the radial field profile;

r is the cylindrical radial coordinate;

ω is the internal angular frequency;

k is the longitudinal (axial) wave number;

n is an integer topological winding number associated with the helicoidal phase structure;

θ is the angular coordinate.

The integer nature of the winding number n ensures the single-valuedness of the field under θ to θ + 2π, endowing the configuration with topological stability.

Also, the longitudinal term kz does not necessarily represent free propagation in external spacetime, but a structural phase gradient along the soliton's internal axis.

Here, τ is a local parameter labeling internal phase evolution at fixed dissipative time T and fixed global phase Θ. Thus, the temporal term ωτ represents an intrinsic phase evolution associated with the

internal dynamics of the helicoidal soliton, which may be interpreted as a proper-time–like parametrized at fixed T.

It is important to note that, in this model, time is not defined by external motion. The intrinsic phase evolution defines an internal temporal parameter that is associated with the internal state of the field. The dependence on τ does not generate physical evolution by itself. Physical ordering is entirely encoded in the monotonic parameter T.

At the present stage, Lorentz invariance is not derived from the microscopic dynamics of the helicoidal field. Rather, it is interpreted as an effective symmetry that emerges only in the large-scale, coarse-grained limit of many interacting solitonic configurations. The framework therefore does not assume Lorentz symmetry as a fundamental principle, but treats it as a statistical and emergent property arising from collective dynamics.

Consistently with this perspective, the variational and dissipative elements employed throughout the model are introduced exclusively at an effective, coarse-grained level. The functional used is not intended to represent a fundamental Lagrangian governing microscopic, time-reversible dynamics. Instead, it should be understood as a configurational functional that organizes and characterizes the selection, stability, and persistence of solitonic states within an intrinsically dissipative and irreversible regime.

Within this effective description, the Rayleigh dissipation term is incorporated phenomenologically and does not originate from a first-principles variational formulation. Its purpose is to capture coarse-grained irreversible energy redistribution, hysteresis, and relaxation effects associated with the interaction between the solitonic structures and the surrounding field environment, rather than to modify or extend a fundamental action principle.

Given this scope, a fully non-equilibrium quantum field-theoretic treatment, such as the Schwinger–Keldysh closed-time-path formalism, lies beyond the objectives of the present work. The effective non-unitarity reflects tracing over unresolved helicoidal micro-degrees of freedom, leading to an emergent open-system description. The model does not seek to resolve microscopic correlation functions or quantum statistical fluctuations far from equilibrium, but instead aims to describe, at a structural level, the emergence, robustness, and longevity of topologically protected dissipative solitonic configurations and collective modes in a non-equilibrium medium.

These clarifications ensure conceptual and internal consistency between the variational description, the phenomenological treatment of dissipation, and the explicitly non-fundamental, emergent character of the formalism adopted herein.

2.4 Helicoidal Oscillation and Dissipation

The internal dynamics of the particle consists of a self-referential helicoidal oscillation in which each cycle fails to close perfectly upon itself in phase space. This persistent phase mismatch generates a continuous, finite, and minimal release of energy without compromising the underlying topological structure. This behavior can be interpreted as a form of helicoidal dynamic hysteresis, in which the system does not return exactly to its initial state after a complete oscillatory cycle.

The energy dissipation per cycle can be expressed as:

$$\Delta E = \oint F \cdot dl \neq 0$$

where $\Delta E > 0 \, per \, helicoidal \, cycle$, indicating that the closed path along the helix does not result in a complete cancellation of the internal forces. Here, dl denotes an infinitesimal element along a closed

trajectory in internal configuration space and should not be confused with the emergent length increment introduced later in Section 5.2.

In this framework, the effective force F does not correspond to a fundamental interaction, but emerges from the dissipative phase dynamics of the helicoidal field, reflecting the system's tendency to locally minimize phase gradients under global topological constraints. Here, too, the closed path is defined in τ parametrized configuration space, while the net energy release accumulates irreversibly along the emergent temporal parameter T.

For fundamental particles such as quarks, electrons, or photons, this effective force should not be interpreted as a classical force in physical space, but as an internal energetic gradient in the configuration of the helicoidal field.

Because the effective force arises from dissipative phase dynamics, it cannot, in general, be derived from a globally defined scalar potential. Dissipation does not originate from interaction with an external environment, but is an intrinsic consequence of the non-closure of the helicoidal phase trajectory.

Despite continuous dissipation, the particle's identity remains preserved due to the conservation of a geometrically defined topological current. Writing the complex helicoidal field in polar form as:

$$\Psi = \rho\, e^{\{i\Phi\}}$$

where:

e is Euler's Number (≈ 2,71828);

ρ is energetic density;

Φ *is the local contiuous phase*.

The associated topological current J is defined by:

$$J^{\mu}{}_{top} = (1/2\,\pi)\,\varepsilon^{\{\mu\nu\lambda\}}\partial_{\nu}\partial_{\lambda}\Phi$$

The same phase field Φ appears both in the polar decomposition of Ψ and in the definition of the topological current. In the latter case, only its singular distributional component contributes.

The parameter ε denotes a real linear growth (or decay) coefficient controlling the local instability of the helicoidal field amplitude. It sets the distance from the stability threshold: ε > 0 corresponds to linear amplification of the field, ε < 0 to damping, and ε = 0 to marginal stability.

This current is identically conserved:

$$\partial_\mu J^\mu{}_{top} = 0$$

independently of the dissipative dynamics governing the field amplitude.

The second derivates are to be understood in the distributional sense, with suportt localized at phase singularities. Here, μ is merely a formal index labeling effective coordinates. It does not refer to physical spacetime.

The conserved topological charge:

$$n=(1/2\pi)\oint \nabla\Phi\cdot dl$$

remains invariant in time:

$$dn / dT = 0$$

ensuring the persistence of particle identity even as energy is irreversibly redistributed into the surrounding fied.

Within this framework, the helicoidal configuration exhibits a finite torsional stability threshold. As internal twisting intensifies, the structure approaches a critical torsion beyond which the helicoidal state becomes dynamically unstable. Although the field itself is fundamentally continuous, energy dissipation does not occur continuously. Instead, it proceeds through discrete relaxation events associated with partial topological slippage and partial release of

accumulated torsional stress. These events preserve the global topological identity of the solitonic structure while introducing an intrinsic form of dynamic hysteresis and temporal irreversibility.

2.5 Self-Confinement, Stability Functional and Non-Conservative Dynamics

The self-confinement of the helicoidal vortex emerges from the balance between the centrifugal pressure associated with the field rotation, longitudinal tension of the helicoidal mode, and the nonlinear self-intereaction terms of the field dynamics. The helicoidal character of the solution is encoded in the phase structure of Ψ, whose gradient generates both azimuthal circulation and axial tension.

Although the microscopic dynamics of the helicoidal field is intrinsically dissipative and does not admit a fundamental Hamiltonian or conservative action principle, long-lived solitonic configurations correspond to statistically stationary states of the underlying non-equilibrium dynamics. Such configurations may be characterized by an effective variational functional, whose extrema identify dynamically persistent and self-confined structures, rather than generating their full temporal evolution.

The effective Lagrangian density may be written as:

$$L=¿\partial\mu\Psi\vee^2-V¿$$

Here, g is the nonlinear self-interaction coupling constant of the helicoidal field. Pjysically, it quantifies the strength of the intrinsic topological self-confinement mechanism, controlling the balance between dispersive spreading, helicoidal tension and nonlinear saturation. Its value determines the stability domain, size scale and energy content of persistent solitonic configurations. The nonlinear self-interaction counterbalances dispersive tendencies, allowing for localized configurations that remain stable under small perturbations.

The corresponding effective action is defined as:

$$S_{eff} = \int d^4x\, L_{eff}(\Psi, \partial_\mu \Psi)$$

or:

$$S = \int L(\partial \mu \Sigma, \omega)\, d^4 x$$

with:

$$\omega = d\Phi / dT$$

Thus we have invariance under global phase shifts. Stability corresponds to a local extremum of this functional:

$$\delta S_{eff} = 0$$

identifying statiscally persistent helicoidal solitons in the steady-state regime. The resulting Euler-Lagrange condition selects stationary field configurations but does not govern the dissipative time evolution of the field, which remains described by the Complex Ginzburg-Landau equation.

Thus, the variational formulation introduced here serves as a stability and selection criterion for self-confined helicoidal solitons within an intrinsically non-conservative and irreversible dynamical framework, rather than as a fundamental action principle.

2.6 Emergent Properties

In this model, fundamental physical properties emerge from the geometry and dynamics of the helicoidal structure. Mass is associated with the energy density of the helicoidal winding, spin corresponds to the internal rotation of the vortex, and charge is related to the orientation and chirality of the helix.

The particle is not an energy carrier, but rather a self-sustained helicoidal field process.

2.7 Dimensional Anchoring of Natural Helicoidal Units

Although the helicoidal-solitonic frame is fundamental at a conceptual level, it implicity contains well-defined physical scales. Each fundamental soliton is characterized by a natural internal energy scale E_0, a characteristic helicoidal oscillation period T_h, and an effective core radius r_h.

These three quantities define a natural system of units intrinsic to the soliton itself. Throughout the following sections, physical quantities may be embased in helicoidal natural units, defined by :

E_0 - expressed as fractions of the soliton’s internal energy;

T_h - measured in helicoidal cycles;

r_h - measured in units of the helicoidal radius.

The helicoidal period T_h represents the emergent internal dynamical timescale of the soliton, and should not be identified with the topological winding number n, although both quantities are related through the internal phase dynamics. In the representations, all emergent geometric, temporal and energetic quantities are measured relative to the internal structure of the solitonic excitation, rather than with respect to an external background manifold.

This choice emphasizes that lenght, time and energy are not primitive concepts in the present model, but relational mechanism derived from the internal dynamics of helicoidal field configurations.

2.8 Consistency with Quantum Principles

The helicoidal-solitonic framework, while fundamentally pre-geometric and dissipative remains conceptually compatible with cores quantum principles. Topological locking of solitons naturally enforces state exclusivity, providing a Pauli-like constraint. Emergent spin arises from orthogonal helicoidal modes, consistent with Dirac’s structural

implications. Interactions derive from phase gradients and dissipative redistribution, reproducing macroscopic analogues of Feynman-mediated forces. Effective Fermi statistics emerge topologically, without explicit weak interactions.

At a coarse-grained level, Heisenberg uncertainty arises naturally from soliton distributions, and Schödinger-like dynamics emerge in weakly dissipative, linearized limits. The model thus provides a topological substrate from which quantum behavior can emerge, without violating established principles.

3. Helicoidal Oscillation, Phase Slippage, and Dissipation

The internal dynamics of a solitonic particle consist of a self-referential helicoidal oscillation, in which the field circulates around its own axis while simultaneously advancing along it. This helicoidal circulation corresponds to a topological winding around the particle axis, associated with its conserved topological charge of the configuration.

This oscillation is not perfectly periodic. Due to nonlinear coupling between amplitude and phase, the system exhibits phase slippage, analogous to that observed in driven vortex systems and Josephson-type dynamics, where phase differences give rise to discrete relaxation events. As a consequence, each oscillation cycle fails to close exactly upon itself in effective phase space. A fraction of the internal energy is irreversibly transferred to the surrounding field, in a continuous but minimal manner, while the soliton remains structurally stable.

Importantly, dissipation does not destroy the particle identity. The relevant conserved quantity is not energy, but topological charge, associated with the winding and linking numbers of the helicoidal flow. As long as these invariants are preserved, the soliton persists. This mechanism provides a natural explanation for irreversibility at the microscopic level, long-term particle stability without invoking perfectly conservative dynamics, and continuous energy exchange between matter and field without particle annihilation.

Although the fundamental field is described by continuous non-linear equations, dissipation does not proceed continuously in time. Instead, it occurs through discrete relaxation events associated with the topological release of accumulated helicoidal tension. We assume that the internal helicoidal oscillation of a fundamental solitonic particle admits a maximum stable torsion. When this critical torsion is exceeded, the configuration becomes dynamically unstable and undergoes a localized phase-slip event.

At a minimal phenomenological level, the energy dissipated in a single relaxation event may be expressed as:

$$\Delta E_{diss} = \eta \Delta \Phi$$

where:

$\Delta \Phi$ is the net phase slip accumulated in the event ($2\pi n$, $n \in \mathbb{Z}$);

η is an effective disspation scale.

This expression does not assume an underlying conservative force or scalar potential, but captures the fact that disspation is directly tied to discrete topological phase rearrangements, rather than smooth energy leakage.

Each such event releases a finite amount of energy and induces an incremental, cumulative separation between previously correlated energy centers, giving rise to emergent spatial structure over time. While the underlying field dynamics remains continuous, the episodic

nature of these relaxation events gives rise to an effectively discrete structure at the emergent level. The resulting discreteness is therefore not imposed a priori, but arises naturally from the nonlinear and topological properties of the helicoidal solitonic field.

Although the effective helicoidal dynamics is intrinsically dissipative, the framework does not require violation of global energy conservation. Dissipation corresponds to an internal redistribution of energy into emergent spatial structural degrees of freedom, rather than true energy loss from the system. This mechanism introduces dynamic hysteresis, ensuring that the soliton remains intrinsically dissipative while preserving its topological identity and long-term stability.

4. Progressive Core Compression, Topological Contraction

Due to ongoing dissipation and phase slippage, the helicoidal soliton undergoes a slow secular evolution. Energy redistribution occurs preferentially in the outer regions of the configuration, while the inner core experiences progressive topological compression. This evolution reflects an internal reorganization of the field, rather than a decay of the solitonic structure.

At the effective level, this process can be described as a gradual reduction of the soliton’s core radius, accompanied by a corresponding increase in the internal phase density. The helicoidal winding becomes increasinly concentrated toward the core, such that the soliton contracts in its topological degrees of freedom, instead of expanding or dispersing. The structure thus becomes more compact in phase space, even as it remains dynamically active.

Importantly, this contraction does not represent a geometric collapse in ordinary physical space. No singularity or loss of coherence is implied. Instead, it corresponds to a tightening of the field's internal winding and linking structure. The soliton remains stable and self-sustained, while its effective interaction cross-section decreases, reflecting the increased concentration of its topological content rather than any instability or fragmentation.

At a minimal prenomenological level, the contraction may be expressed as an inverse relation between the effective core radius r_h and the internal phase density $\rho\Phi$:

$$\rho\Phi = Q / r_h$$

where Q denotes the conserved topological charge associated with the helicoidal winding number. As the dissipation drives a slow decrease of r_h, the phase density necessarily increases, enforcing progressive topological compression while preserving the soliton's identity.

This mechanism provides a natural explanation for long-term structural persistence combined with gradual internal evolution. The soliton becomes increasingly concentrated and inertially stable, not by suppressing dynamics, but by redistributing them into tighter topological configurations. Concentration therefore emerges as a generic outcome of dissipative helicoidal dynamics, rather than as a sign of instability or collapse.

5. Space as Relational Distancing and Emergent Gravity

Consider an ensemble of helicoidal solitons embedded in a continuous field. As each soliton undergoes progressive topological contraction, the effective separation between soliton centers increases, even if the underlying field itself does not expand.

In this framework, what is conventionally interpreted as the expansion of space emerges as a relational effect. Distances increase because matter becomes progressively more internally compact. Space is therefore not a primitive entity, but an emergent geometric measure of topological distancing between solitonic centers. The metric properties of space arise from the collective configuration of field vortices rather than from an independently expanding background.

This perspective aligns naturally with cosmological observations, where expansion is inferred from redshift and relational measurements rather than the literal stretching of a pre-existing spatial container.

This is conceptually similar to the emergent gravity proposal of Erik Verlinde, in which spacetime geometry and gravitation emerge from underlying information and entropic distributions rather than being fundamental. But within this theoretical model, gravity arise from a fundamentally different microscopic mechanism.

5.1 Generation of Space from Helicoidal Dissipation and Energy Redistribution

In the helicoidal–solitonic model, space is not assumed as pre-existing. Instead, it emerges as a consequence of gradual energy dissipation associated with the internal helicoidal oscillation of fundamental particles.

Dissipation in the present framework does not correspond to energy loss from the physical system, but to an irreversible redistribution of energy among distinct sectors of the helicoidal field. The total energy

is conserved globally, while individual solitonic excitations experience a monotonic decrease of internal energy.

We can distinguish three energetic contributions:

$E_s(T)$ is the internal solitonic energy;

$E_f(T)$ is the delocalized field energy;

$E_g(T)$ is the relational (geometric) energy.

Global conservation is expressed as:

$$E_{tot} = E_s + E_f + E_g = \text{constant}$$

where $E_{tot}(T)$ is the total conserved energy of the system.

A fraction of the dissipated energy contributes to the progressive build-up of relational separation between solitonic centers, interpreted as emergent spatial structure.

Each incomplete helicoidal cycle produces a small energy release, ΔE, which induces an incremental separation between previously correlated energy centers, contributing incrementally to the emergent temporal parameter T through irreversible dissipation. This separation is interpreted as the effective generation of spatial distance.

To formalize this process, a scalar separation field $\Sigma(T)$ is introduced, defined as the accumulated normalized dissipation. Here, Σ depends exclusively on the dissipative parameter T and is independent of the global phase axis Θ. As a scalar separation field, it acts as the foundational quantity from which an effective spatial metric emerges. It represents the fraction of internal energy dissipated irreversibly through incomplete helicoidal cycles. Within this model, it can be represented either continuously or discretly.

The scalar separation field is defined as:

$$\Sigma(T) = (1 / E_0) \int_0^T \Delta E(T') \, dT'$$

where E_0 is the characteristic internal energy of the solitonic structure. Thus, for the accumulated dissipation of the scalar field, we have:

$$\Sigma(T) = 1 / E_0 \, \Sigma_{n=1}^{N(t)} \, \Delta E_n^{diss}$$

In the continuum limit, the accumulated dissipation defines the continuous derivative:

$$\Sigma'(T) = d\Sigma / dT = 1 / E_0 \, (dE_{diss} / dT)$$

Alternatively, in discrete form, for N cycles, the incrementation defines the derivative:

$$\Sigma = \Sigma_n \, \Delta \, E_n / E_0$$

or equivalently:

$$\Delta\Sigma n = \Delta E_n^{diss} / E_m$$

where ΔE_n^{diss} denotes the dissipation per cycle.

Here, we have:

$$\Sigma(T) = \Sigma N(T) \Delta\Sigma n$$

The continuous derivative represents the instantaneous rate of separation growth, while the discrete derivative describes finite steps per helicoidal cycle. Both converge in the limit of infinitesimal cycles, linking microscopic soliton dynamics to the emergent metric description.

To clearly distinguish between the dissipation rate and the discrete dissipation per cycle, we may write:

$$\Sigma'(T) = (1 / E_m) \, E'_{diss}(T)$$

E_m denotes the mean internal energy per helicoidal cycle, with $E_0 = N \cdot E_m$ in the continuum limit.

The emergent distance R between two helicoidal entities evolves according to:

$$dR \propto d\mathrm{T} \cdot \alpha(\Delta E / E_0)$$

where α is a geometric conversion coefficient relating dissipated energy to effective spatial separation. It encodes the mean phase slippage per topological cycle and is therefore dimensionless. The R(T) represents an emergent relational distance, as a separation between solitonic centers, defined operationally via accumulated dissipation rather than embedding coordinates. In the coarse-grained and isotropic limit, the relational separation R is represented by a continuous radial variable r, which serves as the argument of effective fields and potentials.

Importantly, we can refer to the equation above as a law governing emergent spatial separation. Again, this relation acts strictly along T. The global phase coordinate Θ we will consider later does not enter the metric structure.

Here, α may be derived as:

$$\alpha = (1/ 2\pi \cdot (\mathrm{d}\Phi / \mathrm{dN})$$

where:

Φ is the internal helicoidal phase;

N is the number of topological cycles.

This relation above defines the helicoidal phase-slippage law governing the emergent temporal and dissipative structure of the theory and constitutes a central structural equation of the model. Here, this phase slippage does not correspond to energy loss.

Within this framework, the scalar field Σ may be defined over a simplicial complex as:

$$\Sigma : V \rightarrow S^1$$

with discrete derivatives given by:

$$\partial_i \Sigma \rightarrow \Delta_{ij} \Sigma$$

Here, V represents the set of solitonic centers, allowing for a topological description of emergent space without assuming a continuous embedding. This decoupled structure is naturally encoded by the Kronecker delta Δ_{ij}, which enforces diagonal contributions in the discrete index space, ensuring that only coincident modes contribute to the effective dynamics.

5.2 Emergent Metric and Effective Background

The emergence of spatial separation in the present framework is formalized through the introduction of a scalar separation field, denoted by $\Sigma(x, T)$. This field represents the locally accumulated and normalized dissipation density arising from irreversible phase slippage in interacting helicoidal solitons. Relational distances between solitonic centers are defined operationally via spatial gradients of Σ, rather than by reference to a pre-existing geometric background.

Additionally, Σ should be understood as a historical functional defined over the interaction graph, which admits continuous representations in the thermodynamic limit.

As dissipation-driven separations $\Delta\ell$ accumulate across an ensemble of solitons, an effective metric background is statistically induced. This metric is not postulated a priori, but emerges from the collective organization of dissipative interactions within the solitonic network.

Thus we have:

$$\Delta\ell \equiv a\,(\Delta E_{diss} / E_o)$$

with $\Delta\ell$ interpreted as a relational separation increment generated by phase slippage disspation.

The resulting background is dynamic, depending explicitly on soliton density, dissipation rate, and long-term energy redistribution. This mechanism is conceptually analogous to emergent metrics in elastic media, networked systems, and entropic gravity approaches, where

internal degrees of freedom reorganize into effective geometric structures.

At the effective level, the emergent spatial line element is written as:

$$ds^2 = g^{eff}_{ij} dx^i dx^j$$

where the effective metric tensor is defined through coarse-grained correlations, as an average distribution, of the separation field:

$$g^{eff}_{ij} = \langle \partial_i \Sigma \cdot \partial_j \Sigma \rangle$$

Here, $\partial_i \Sigma$ denotes the partial derivative of Σ with respect to the i-th spatial coordinate, and the brackets $\langle \cdot \rangle$ indicate a statistical average over many interacting solitons.

Equivalently, we may admit a single admissible bilinear tensor structure of the form:

$$g_{ij} = \lambda \langle \partial_i \Sigma \cdot \partial_j \Sigma \rangle$$

where λ is a proportionality constant encoding normalization and scale-setting conventions. This formulation emphasizes that the emergent geometry arises from collective correlations among multiple energy centers, not from the internal structure of any individual soliton. The effective metric is Riemann-like in the sense that it defines a symmetric bilinear form over relational gradientes, without assuming an underlying differentiable manifold or Levi-Civita connection.

Importantly, the spatial derivatives $\partial_i \Sigma$ are not defined with respect to coordinates on an underlying differentiable manifold. Instead, they represent coarse-grained relational gradients defined over the solitonic network itself. Consequently, the metric encodes statistical correlation structure rather than intrinsic geometry, reinforcing the relational and emergent character of space in this model.

Regarding physical scales, we can apoint heuristic values merely as order-of-magnitude estimative. If the dissipated energy per cycle is on

the order of $\Delta E \approx 10^{-13}$ J (comparable to a fraction of the proton rest energy), and the soliton density is comparable to nuclear matter densities ($\approx 10^{44}$ m^{-3}), variations in Σ would initially manifest at subatomic scales. Over billions of oscillatory cycles, these incremental separations can accumulate, effectively building up macroscopic and eventually cosmological distances. The conversion efficiency from phase dissipation to effective distance may be encoded in a dimensionless parameter α, expected to be extremely small ($\alpha \approx 10^{-20}$–10^{-15} per cycle), consistent with the slow, large-scale emergence of effective space.

In this formulation, geometry is neither fundamental nor static, but a relational, statistical construct emerging from the long-term dissipative dynamics of solitonic matter.

5.3 Interactions as Phase Couplings

Particle interactions arise from the coupling of helicoidal phases between nearby structures. Constructive or destructive interference produces effective forces, depending on the relative alignment of phases.

The interactions between solitons are modeled by an interaction Hamiltonian:

$$H_{int} = - J\cos(\Delta\Phi(r; \Theta))$$

where J is the coupling strength and $\Delta\Phi(r; \Theta)$ is the relative phase difference between helicoidal oscillations as a function of the solitons' relative positions r. Phase diferences are evaluated relative to the globar phase reference Θ, while forces emerge from spatial gradientes accumulated along T.

The H_{int} denotes an effective, coarse-grained interaction Hamiltonian describing phase-mediated couplings in the dissipative regime.

Additionally, J may depend on the relational distance R, given by:

$$J = J(R)$$

The resulting effective force on a soliton is:

$$F = -\nabla H_{\int ¿¿} = J\sin(\Delta\Phi(r))\nabla\Delta\Phi(r)$$

Here, effective force corresponds to dissipative phase current $J\Phi$. The operator ∇ should be understood as a gradient in relational configuration space, defined over the network of solitonic separations rather than over a pre-existing geometric manifold.

Thus:

$$\Delta E = \oint J\Phi \cdot dl$$

It arises from the gradient of the coupling energy. These interactions emerge naturally from the spatial variation of the phase difference, producing attractive or repulsive forces depending on whether the interference is constructive or destructive.

For ensembles of multiple solitons, the total Hamiltonian is the sum of pairwise interactions:

$$H_{total} = \Sigma i<j - Jij\cos(\Delta\Phi ij(ri, rj))$$

and the force on the i-th soliton is:

$$F_i = -\nabla_i H_{total}$$

This formulation ensurres that all forces are emergent from the geometrical configuration and phase dynamics of the helicoidal field, without requiring mediating particles.

The interaction Hamiltonian introduced here should be understood as an effective, coarse-grained description of phase-mediated interactions in the dissipative regime, rather than as a fundamental microscopic Hamiltonian.

5.4 Emergent Attractive Potential

Helicoidal dissipation generates a spatial separation gradient that tends to minimize the total energy of the system. This process produces a universal attractive interaction between solitons, independent of their charge or chirality.

This interaction does not correspond to a fundamental force, but rather to a collective dissipative effect, arising from phase slippage, energy redistribution, and long-range coherence in the helicoidal medium.

The effective attractive interaction potential can be approximated by an expression proportional to the product of the soliton energies, where E_1 and E_2 are the energies of the solitons and α is an emergent coefficient dependent on the density of the helicoidal background:

$$V(r) \approx \alpha(E_1 E_2)/r$$

Here V denotes an effective interaction energy (or potential), defined as the volume-integrated reduction of dissipative losses due to overlapping phase gradients.

At large scales, the collective phase interactions generate an effective attractive potential of the Newton-like form:

$$V(r) = \frac{-G_{em}(E^1 E^2)}{r}$$

where $r$is the separation distance and $G_{em}$is an emergent coupling constant determined by the statistical and topological properties of the helicoidal field network.

The emergent coupling constant G_{em} (or α¿ is determined by the soliton density, phase coherence length, and topological winding number, reflecting an effective averaging over collective interactions.

At this stage, the Newton-like form is introduced as a large-scale phenomenological approximation, capturing the collective effect of

helicoidal dissipation. A first-principles derivation may be addressed in future work.

Thus, we assume the concept of gravity as an emergent, statistical effect rather than a fundamental force. In this model, gravitation is a macroscopic manifestation of microscopic phase coherence and dissipative dynamics.

5.5 Heuristic Derivation of the 1/r Attractive Potential

Consider two solitonic excitations embedded in a dissipative helicoidal medium. Each soliton locally perturbs the phase structure of the field, generating gradients in the helicoidal phase and energy density. These gradients propagate through the medium and relax via dissipation. Dissipative relaxation tends to minimize spatial phase mismatches, driving the system toward configurations of lower total dissipation.

We introduce the calligraphic symbol $\mathcal{D}$ to denote the helicoidal dissipation density. The quantity $\mathcal{D}(x, T)$ represents the local, coarse-grained density of irreversible energy redistribution arising from helicoidal phase slippage, defined per unit volume and per unit emergent dissipative time. Let $\Phi(r)$ denote the coarse-grained effective helicoidal phase field, obtained by statistical averaging of internal solitonic phases in the dissipative regime. The local dissipation rate may be written phenomenologically as:

$$\mathcal{D} \propto (\nabla \Phi)^2$$

Or even:

$$\mathcal{D}(x) = 1 / E_0 \, (dE_{diss} / dV \, dT')$$

where:

$\mathcal{D}$ is the helicoidal dissipation density;

T’ is a dissipative emergent time;

E_0 is the soliton internal energy.

For an isolated soliton with energy E, the induced phase perturbation spreads isotropically through the medium.

In the stationary dissipative and isotropic regime, phase perturbations behave as effectively conserved fluxes at large scales. In three spatial dimensions, conservation of phase flux implies that the magnitude of the phase gradient decreases with distances as:

$$|\nabla \Phi| \approx E / r^2$$

Now consider two solitons with energies E_1 and E_2. The overlap of their phase gradients produces a cross-term in the total dissipation:

$$\Box_{int} \propto \nabla \Phi_1 \, . \, \nabla \Phi_2,$$

$$\Box_{int} \propto E_1 \, E_2 / r^4$$

The interaction energy corresponds to the integrated dissipation reduction over the intervening volume:

$$V(r) \approx \int \Box_{int} \, dV$$

We obtain the integral:

$$V(r) \approx \int^{inf}_{r} E_1 \, E_2 / r'^4 \, 4\pi r'^2 \, dr' \approx E_1 \, E_2 / r$$

Thus, the inverse-distance attractive potential emerges naturally from isotropic phase propagation, geometric dilution of helicoidal gradientes and minimization of total dissipation loss. No fundamental force law is assumed here.

The 1/r behavior arises as a geometric and dissipative consequence of the medium. The inverse-distance dependence naturally comes from long-range phase correlations in three-dimensional helicoidal media, analogous to Green-function behavior in diffusive systems.

Additionally, we may define the effective mass as:

$$m = \partial E / \partial \omega_{int}$$

Here, ω_{int} is not relativistic frequency, but an internal parameter of the helicoidal field. The partial derivative $\partial E/\omega_{int}$ denotes the local energetic stiffness of the solitonic configuration with respect to infinitesimal variations of the internal helicoidal parameter ω_{int}, evaluated in the stationary dissipative regime and does not refer to finite variations between discrete cycles.

This is another relation crucial in the present framework. The definition introduces an effective inertial mass associated with internal helicoidal dynamics.

With this, we obtain:

$$F = - \nabla \Phi \rightarrow a = F / m$$

Here Φ plays the role of an effective interaction potential emerging from dissipative phase gradients rather than a fundamental gravitational potential.

We can understand that the equivalence between inertial and gravitational masses emerges only in the stationary dissipation regime.

5.6 Connection with Entropic Gravity

The emergent attractive interaction derived above admits a direct interpretation within the framework of entropic gravity. As in entropic gravity, gravitational attraction is not fundamental, but arises from the statistical tendency of systems to increase entropy.

In the present model, entropy increase is not postulated independently. Instead it follows from irreversible helicoidal dissipation and phase decoherence. The helicoidal medium possesses a large number of microscopic phase configurations, and separations correspond to different macrostates of this phase network.

Let S denote the coarse-grained entropy associated with the number of accessible helicoidal phase configurations. Spatial separation between solitons increases phase mismatch and dissipative pathways, enlarging the configuration space and raising entropy gradients:

$$\nabla S \propto \nabla \square$$

In this sense, the emergent force can be written in entropic form:

$$F = T_{eff} \nabla S$$

Because helicoidal phase gradients dilute as $1/r^2$, the associated entropy gradient scales similarly, yielding an effective force:

$$F(r) \propto E_1 E_2 / r^2$$

and thus:

$$V(r) \propto - E_1 E_2 / r$$

However, unlike phenomenological entropic gravity models, where entropy is introduced axiomatically, we derive entropy, temperature and force from a deeper dynamic substrate: irreversible helicoidal phase dissipation. Gravity thus appears as a macroscopic statistical regularity emerging from microscopic topological and dissipative processes.

5.7 Helicoidal Gravitation

From the formulations above we can derive the gravitational potential Φ_g:

$$\nabla^2 \Phi_g = - k \square$$

where k is a helicoidal-field structural constant, given as a physical approximation. ∇^2 is an effective Laplacian induced by the emergent $\sum$-metric discussed previously.

This equation may be understood as an coarse-grained Poisson-like relation, valid in the statistical limit of many interacting solitons.

Thus:

$$F_g = - \nabla \Phi_g$$

Importantly, we can derive mass from helicoidal dissipation. Since internal dissipation is proportional to helicoidal compression, compression defines emergent mass.

Thus we have:

$$m_{em} = v_h \int \Box \, dV$$

Here, v_h is a helicoidal structural constant, denoting the characteristic propagation velocity of helicoidal dissipation gradients in the stationary regime. It sets the causal scale for irreversible energy redistribution within the helicoidal medium and encodes its effective rigidity.

With this formulation, mass ceases to be a primary quantity and instead emerges as a stationary state of dissipation. Stationarity corresponds to a dynamic balance between compressive effects and dissipative losses. Mass is therefore reinterpreted as an integral measure of dissipation, rather than as a fundamental parameter. The helicoidal structural constant plays the role of a limiting speed at the effective level, without being identified with the fundamental speed of light.

We can formalize:

$$M = 1 / v_h^2 \int \Box(x) \, d^3x$$

and even:

$$F_g = - \nabla \int^T_0 \Box(x,T') \, dT'$$

This is a non-Markovian effective description. The factor v_h^2 plays the role of an effective energetic stiffness of the helicoidal medium, converting accumulated dissipation into inertial mass.

Within this framework, gravity is not treated as a fundamental interaction, but rather as an emergent phenomenon arising from the statistical flux of topological dissipation within a coherent helicoidal medium.

Gravitational effects correspond to a spatial gradient of the accumulated dissipative history, encoding the integrated irreversibility of the underlying field dynamics.

5.8 Solution for Spherical Symmetry

For an approximately isotropic soliton, we take:

$$\Sigma(r) = \Sigma_0 \, \delta(r)$$

The delta-like dissipation profile represents the point-like limit of a highly compact solitonic configuration, valid at distances much larger than the internal helicoidal scale, i.e., $r >> r_h$.

We then obtain the equation:

$$\nabla^2 \Phi_g = - \kappa \, \Sigma_0 \, \delta(r)$$

Its solution is:

$$\Phi_g(r) = - \kappa \, \Sigma_0 / 4\pi r$$

Given the force:

$$F_g(r) = - \kappa \, \Sigma_0 / 4\pi r^2$$

We thus obtain:

$$G_{em} = \kappa / 4\pi v_h^2$$

Here we observe that Newtonian gravity can emerge naturally, rather than being postulated.

With this formulation, no fundamental dimensional constants are introduced ad hoc. All effective couplings arise as ratios between intrinsic helicoidal scales.

6. Emergent Arrow of Time, Dissipation and their Mathematical Structure

In this framework physical time is identified with the cumulative direction of helicoidal dissipation. Each incomplete cycle defines an irreversible increment of the internal temporal parameter.

The arrow of time arises naturally from the condition of monotonically increasing dissipation. Temporal reversal would require the perfect reconstruction of the helicoidal phase, which is topologically forbidden for dissipative systems.

6.1 Definition of the Dissipative Phase Space

Consider a helicoidal soliton characterized by an internal phase $\Phi(\tau) \in S^1$ and an internal energy functional $E[\Phi]$. The system evolves on a reduced phase space $\mathcal{M} = S^1 \times \mathbb{R}^+$, where $\mathbb{R}^+$ represents the non-negative dissipated energy.

We have:

$$H^1(\mathcal{M}) \neq H^1(S^1)$$

Thus :

$$H^1(S^1 \times \mathbb{R}^+) =\sim H^1(S^1)$$

The infinitesimal evolution of the phase is given by:

$$d\Phi = \omega d\tau - \gamma(\Phi)\, d\tau$$

where ω is the intrinsic angular frequency and $\gamma(\Phi) \geq 0$ encodes dissipative phase slippage.

6.2 Emergent Temporal Parameter

Let $\Delta E(\tau) \geq 0$ represent the dissipated energy per incomplete helicoidal cycle and define the dissipated energy per cycle as:

$$\Delta E(\tau) = \gamma(\Phi)\, E_0$$

where E_0 is the characteristic internal energy scale. The internal temporal parameter T is defined as the cumulative normalized dissipation:

$$T(\tau) = (1 / E_0) \int_0^\tau \Delta E(\tau')\, d\tau' = \int_0^\tau \gamma(\Phi(\tau'))\, d\tau'$$

Since $\gamma(\Phi) \geq 0$ almost everywhere:

$$dT / d\tau = \gamma(\Phi(\tau)) > 0$$

except possibly on a set of measure zero. Therefore, T defines a strictly monotonic ordering parameter on $\mathcal{M}$.

Here the positivity of γ is not imposed ad hoc, but follows from the stability condition of helicoidal solitonic configurations, ensuring bounded energy density.

Also, by construction:

$$dT / d\tau = \Delta E(\tau) / E_0 > 0$$

This inequality guarantees monotonicity, establishing a natural arrow of time without invoking external temporal axioms.

Here, as we considered, τ is an auxiliary evolution label. It carries no physical meaning by itself. As for T, it represents a physical temporal ordering defined by the emergent variable.

Also, the temporal parameter T is not identified with the relativistic coordinate time of Minkowski spacetime, since it is associated internally with irreversible helicoidal dynamics. Lorentz symmetry is not postulated at the microscopic level, but is expected to emerge statistically in the long-wavelength, weak-dissipation regime, where

phase slippage averages out and effective relational distances become approximately homogeneous and isotropic.

6.3 Topological Obstruction to Time Reversal

The phase Φ defines a mapping:

$$\Phi : C \to S^1$$

where C is a closed trajectory in configuration space. The associated winding number is:

$$w = (1 / 2\pi) \oint_C d\Phi$$

For dissipative helicoidal dynamics:

$$d\Phi \neq \text{exact}$$

or not globally exact on $\mathcal{M}$ and therefore $w \neq 0$ generically. If the system possesses a non-zero topological winding number w:

$$w = (1 / 2\pi) \oint \nabla\Phi \cdot d\ell \neq 0$$

then $\Delta\Phi_{total}$ cannot vanish globally, even in closed trajectories. This enforces temporal irreversibility through topological constraints.

Beside this, each helicoidal cycle is characterized by a phase $\Phi \in [0, 2\pi)$. Dissipation prevents perfect phase closure, leading to a residual phase defect $\delta\Phi$ per cycle:

$$\Phi_n = 2\pi n + \delta\Phi_n$$

with:

$$\delta\Phi_n \neq 0$$

The accumulated phase defect after N cycles is:

$$\Delta\Phi_{total} = \oint d\Phi = 2\pi w + \Sigma_n \delta\Phi_n$$

A global time-reversal operation would require:

$$\Phi(t) \to \Phi(-\tau)$$

where:

$$\gamma \to -\gamma$$

which is forbidden since $\gamma \geq 0$ by construction.

Here the positivity of γ is not imposed ad hoc, but follows from the stability condition of helicoidal solitonic configurations, ensuring bounden energy density and preventing phase runaway.

Additionally, no diffeomorphism exists on $\mathcal{M}$ that reverses T while preserving the equations of motion.

6.4 Cohomological Interpretation

We introduce the non-exact 1-form, defined on the extended phase manifold $\mathcal{M}$:

$$\chi = d\Phi - \omega d\tau$$

In the absence of dissipation, this 1-form would be closed and locally exact. However, once dissipative effects are incorporated, the phase evolution acquires a non-conservative contribution, encoded by a phase-dependent damping function $\gamma = \gamma(\Phi)$. As a direct consequence, the exterior derivate of χ no longer vanishes, and we obtain:

$$d\chi = - d\gamma \wedge d\tau \neq 0$$

Since the dissipation funciton depends solely on the phase variable, its diferencial can be writen explicitly as:

$$d\gamma = (d\gamma / d\Phi)\, d\Phi$$

Thus we obtain:

$$d\chi = - (d\gamma / d\Phi)\, d\Phi \wedge d\tau$$

From an equivalente dynamical perspective, the phase diferencial itself may be rewriten incorporating the dissipative contribution explicitly, as:

$$d\Phi = \omega d\tau - \gamma(\Phi)\, d\tau \;\equiv\; (\omega - \gamma(\Phi))\, d\tau$$

where:

$$d\Phi / d\tau = \omega - \gamma(\Phi)$$

Although the 1-form χ is not closed due to the presence of dissipation, its $d\Phi$ component nevertheless defines a non-trivial element of the first cohomology $H^1(\mathcal{M})$. The non-vanishing of $d\chi$, acting as cohomology obstruction, prevents global exactness and, at the same time, induces a preferred orientation on the phase bundle, providing a topological invariant associated with a non-trivial cohomological structure and temporal directionality.

This obstruction, being topological in nature, defines an invariant tied to dissipative dynamics. The emergent arrow of time corresponds to the orientation of this cohomology class, an orientation that is not arbitrary but is uniquely fixed by the sign and functional structure of the dissipation term $\gamma(\Phi)$.

6.5 Entropy Production and Temporal Orientation

We define entropy production as:

$$dS = \beta\, \Delta E$$

where β is an effective inverse temperature parameter of the helicoidal background. Then:

$$dS / dT = \beta\, E_0 \geq 0$$

demonstrating that entropy increase is a corollary of the emergent temporal parameter rather than its cause. This show consistency with thermodynamic irreversibility while grounding the arrow of time in microscopic phase dynamics rather than statistical postulates.

Thus, time emerges as a directed ordering parameter defined by cumulative helicoidal dissipation and protected by phase topology.

6.6 Temporal Irreversibility

Since an emergent temporal variable is defined:

$$T = \int \Delta E \, d\tau$$

which naturally satisfies:

$$dT/d\tau > 0$$

this establishes a directional arrow of time, directly linked to irreversible helicoidal dissipation.

Non-zero topological winding numbers introduce a cumulative phase shift:

$$\Delta \Phi_{\text{total}} \neq 0 \; for \; n \neq 0$$

ensuring temporal irreversibility even in closed interaction cycles.

Time reversal would require:

$$\Delta E \rightarrow -\Delta E \quad \text{and} \quad \delta \Phi_n \rightarrow 0 \quad \forall \, n$$

which is forbidden for dissipative systems with non-trivial topology. Therefore, the temporal arrow is protected both energetically and topologically.

6.7 Summary

The arrow of time here arises as a mathematically protected structure resulting from positive-definite dissipation, non-exact phase evolution, non-trivial topological winding and non-vanishing cohomology class on the reduced phase space.

Temporal irreversibility is therefore a geometric and topological property of helicoidal solitonic dynamics, not a statistical postulate.

7. Global Phase Correction

Building upon the emergent temporal structure introduced in Section 6, we introduce the concept of Global Phase Correction (GPC).

Throughout this section, the previously mentioned three distinct parameters are employed.

The symbol τ denotes a local descriptive parameter used solely for convenience in dynamical expressions, without physical interpretation.

The internal temporal parameter T provides a strictly monotonic ordering associated with irreversible and cumulative helicoidal dissipation. However, by itself, it does not ensure global phase coherence or long-term stability of solitonic configurations.

The variable Θ denotes a global phase–temporal ordering parameter associated with collective synchronization. Governing collective synchronization across the helicoidal field, it acts as a regulatory principle. It continuously corrects local phase deviations while preserving the intrinsic irreversibility imposed by dissipation.

Under the action of the GPC, phase mismatches among helicoidal solitons are progressively reduced along the global phase axis Θ. When a population of solitons approaches partial or near-critical synchronization, collective field instabilities may arise, enabling the nucleation of new solitonic configurations.

The GPC therefore constitutes a collective ordering principle complementary to the local dissipative time T. It establishes an emergent structure governing long-range coherence without negating the arrow of time defined by irreversible dynamics.

Both T and Θ are internal ordering parameters defined on the solitonic phase bundle and do not enter the spacetime metric, leaving relativistic causality untouched. In this sense, Θ plays a role analogous to a renormalization-group flow parameter, organizing collective phase coherence across scales rather than defining physical time.

While the Global Phase Correction shares a formal analogy with Kuramoto-type synchronization models at the level of phase dispersion reduction, the underlying mechanisms are fundamentally distinct. Kuramoto synchronization results from mutual coupling among oscillators evolving in a single external time parameter. By contrast, the present framework employs two emergent internal ordering parameters: a strictly monotonic dissipative temporal coordinate T, and a global phase ordering axis Θ, evaluated on fixed-τ phase configurations. No evolution, signal propagation, or causal influence occurs along Θ, which instead serves as an emergent organizational axis governing long-range coherence. Consequently, the GPC cannot be reduced to a Kuramoto-type dynamics.

The Global Phase Correction introduced here anticipates the Universal Quantum Correction concept compatible with the Retro-Expansion Theory and the present helicoidal–solitonic field framework, providing a mechanism for long-term coherence, regeneration, and structural stability within the model.

7.1 Global Phase Ordering Axis

This phenomenon arises when microscopic deviations in phase, energy density, or topology are continuously regulated by the interaction between the irreversible temporal parameter T and the global phase coordinate Θ.

Consider that each helicoidal soliton possesses an internal phase $\Phi(t) \in S^1$ and an emergent temporal parameter T, defined by cumulative

dissipation. We now introduce the parameter Θ, defined as the collectively synchronized phase of the soliton ensemble:

$$\Theta = \Omega^{-1} \oint \Phi_i \, d\mu(i)$$

where Ω is the global balance frequency and μ(i) represents the normalized measure over the set of synchronized modes. Additionally, Ω here should not be understood as a new constant ad hoc, but as another structural parameter.

We assume that the measure μ(i) is normalized such that:

$$\oint d\mu(i) = 1$$

The parameter Θ defines a global phase ordering axis, independent of relativistic proper time and of the parameter T.

Here, the phase-ordering axis Θ does not correspond to a physical temporal coordinate and does not enter the spacetime metric. Therefore, no violation of Lorentz invariance or relativistic causality is implied.

Let each solitonic particle be characterized by an internal phase $\Phi i(\tau)$, while simultaneously participating in a global oscillatory balance described by Θ(τ).

Here, the parameter τ serves only as a labeling variable for instantaneous phase configurations. Physical evolution occurs exclusively along the dissipative temporal ordering T, while Θ is a collective functional evaluated on phase configurations at fixed τ. In the equation Θ may be parametrized with respect to τ or T for descriptive purposes, without implying temporal causation. The dependence on τ is purely parametric, serving only to label instantaneous phase configurations. No physical evolution is generated along τ.

We can define the phase deviation:

$$\delta\Phi_i(\tau) = \Phi_i(\tau) - \Theta(\tau)$$

The Global Phase Correction acts to minimize $\delta\Phi_i$ through enhanced local dissipation:

$$d(\delta\Phi_i) / dT = -\kappa\, \delta\Phi_i + \xi_i(T)$$

where $\kappa > 0$ can be an effective universal correction coefficient and $\xi_i(T)$ represents bounded stochastic fluctuations induced by nonlinear field interactions.

Here $\xi_i(T)$ is not classical thermal noise, but an internal dynamics of the helicoidal field. The stochastic term does not satisfy a classical fluctuation-dissipation relation. Its statistical properties are determined internally and may be non-Markovian.

7.2 Minimal Coherence Interval

The minimal coherence interval here is defined as the smallest resolvable increment of Θ:

$$\Delta\Theta_{min} = 2\pi / N_{sync}$$

where N_{sync} is the effective number of synchronized modes.

The existence of a minimal increment $\Delta\Theta_{min}$ implies that correction events are intrinsically discrete, providing a natural lower bound for temporal resolution without postulating fundamental quantum operators.

Importantly, this minimal coherence interval would correspond to a universal present instant. The interval could represent a quantum of universal present, common to all particles coupled to an effective and collective quantum balance.

7.3 Universal Correction Operator

A universal correction operator $\hat{C}$ acting on the effective state Ψ is introduced:

$$\partial \Psi / \partial \Theta = - \hat{C} \Psi$$

with:

$$\hat{C} = \kappa \, (\Phi - \langle \Phi \rangle \Theta)$$

where $\kappa > 0$ is a coupling constant and $\langle \Phi \rangle \Theta$ is the synchronized mean phase. This operator enforces the dynamical feedback of individual phases toward collective equilibrium.

Here, Φ should be understood as an effective phase functional acting multiplicatively on Ψ. Additionally, as we defined early, Ψ is an effective coarse-grained state functional, not a Hilbert-space wavefunction. The equation corresponds to a relation of renormalization-like or coherence flow.

7.4 Quantized Stability and Discrete Correction Cycles

Because admissible solitonic states are constrained by discrete topological invariants $n_i \in \mathbb{Z}$, phase correction does not occur continuously but in finite corrective steps associated with phase slips:

$$\delta \Phi_i \rightarrow \delta \Phi_i - 2\pi k$$

with $k \in \mathbb{Z}$. These correction events define quantized adjustment cycles, each corresponding to a minimal global phase interval $\Delta \Theta_{min}$.

The effective temporal resolution of physical processes is therefore bounded below by:

$$\Delta T_{min} = \Delta \Theta_{min} / \Omega$$

Eventually, Ω may be interpreted as the universal oscillation frequency.

7.5 Relation to Dissipation and Irreversibility

The operator $\hat{C}$ does not act on relativistic proper time, but solely along the Θ axis. Helicoidal dissipation enforces strict monotonicity

along the temporal coordinate T, whereas Θ serves as a global correction coordinate, permitting phase coherence without violating local irreversibility.

Accordingly, the GPC proceeds irreversibly along the dissipative temporal axis T, while remaining globally synchronized along the universal phase axis Θ. The correction process is therefore directional and cumulative, reinforcing the emergent arrow of time while preserving global phase coherence.

Importantly, since Θ is evaluated on fixed-τ configurations and does not propagate signals, no causal influence can be transmitted along Θ.

7.6 Physical Interpretation

The Global Phase Correction may be understood as an emergent principle of temporal consistency, whereby local fluctuations are continuously realigned through a global phase structure. This points to a topological basis for the stability of physical laws and for the observed uniformity of quantum time.

From this perspective, quantum behavior emerges as a regulatory property of a continuous field, shaped by global phase synchronization, irreversible dissipation, and topological discreteness.

Accordingly, features traditionally ascribed to fundamental quantum operators, such as the stability of energy levels, the suppression of divergences, and the persistence of particle identity are reinterpreted as collective manifestations of the Global Phase Correction.

8. Collective Synchronization, Particle Creation and Antimatter

This section reformulates particle creation and antimatter within the helicoidal–solitonic framework, aligned with standard Quantum Filed Theory language while preserving the underlying geometric and dissipative ontology.

Throughout this section, a single temporal parameter T is employed consistently, representing the emergent internal time defined by cumulative helicoidal dissipation, as introduced in Sections 6 and 7. Any auxiliary descriptive parameters are suppressed for clarity.

Within this framework, particle creation arises from collective synchronization phenomena within an ensemble of helicoidal solitons, rather than from local operator insertions acting on a predefined vacuum. Partial phase locking across the population enables coherent collective modes extending over spatially separated regions of the field. These modes behave as effective long-range correlations of the underlying field configuration.

From a QFT perspective, such modes play a role analogous to nonperturbative vacuum excitations or collective order parameters, allowing energy previously dispersed across delocalized field degrees of freedom to re-localize into stable excitations. Particle creation is thus interpreted as a resonant, topology-driven reconfiguration of the field rather than a point-like spacetime event.

This formulation avoids ultraviolet singularities and does not require fundamentally discrete creation and annihilation operators. Quantization emerges effectively from collective coherence, topological constraints, and dissipative dynamics, suggesting compatibility with a universal correction mechanism associated with global field organization.

8.1 Phase Coherence Threshold and Nucleation Condition

Let a population of N helicoidal solitons be characterized by internal phases $\Phi_i(\tau)$. We define the coherence order parameter:

$$C(\Theta) = (1 / N) \Sigma_{i=1}^{N} \exp(i\Phi_i(\tau))$$

The nucleation process is not arbitrary, but occurs only when collective phase coherence exceeds a critical threshold. This allows the formulation of an explicit nucleation condition, expressed in terms of a global coherence parameter.

A collective instability capable of nucleating arises when:

$$|C(\Theta)| \geq C_c$$

where C_c is a critical coherence threshold determined by the nonlinear response of the background field. It corresponds to the critical value at which the linearized incoherent state becomes unstable.

When the condition is met, phase locked oscillations induce constructive interference in the surrounding medium, allowing energy stored in extended modes to self-focus into a new localized helicoidal vortex. The resulting soliton inherits its characteristic frequency, winding number and chirality from the dominant coherent mode.

In this process, the global evolution is governed by T, while τ indexes the local internal phase of each soliton. The critical coherence threshold C_c involves collective ordering, implicitly related to global phase ordering Θ.

8.2 Topological Selection and Stability of Created Particles

Not all coherent instabilities result in stable particle creation. A newly nucleated soliton must satisfy a topological compatibility condition with integer winding number:

$$n_{new} \in \mathbb{Z}$$

where:

$$|n_{new}| \geq 1$$

Configurations violating this condition are dynamically unstable and decay into delocalized field modes.

8.3 Antimatter as Conjugate Helicoidal Structures

Antimatter corresponds to solitons of opposite helicoidal chirality, characterized by reversed phase winding $n \rightarrow -n$.

Equivalently, if a particle is associated with a phase evolution:

$$\Phi(\theta, \tau) = n\theta + k\tau - \omega\tau$$

the antiparticle phase is:

$$\Phi(\theta, \tau) = -n\theta + k\tau - \omega\tau$$

Here τ indexes the local internal phase evolution, while ω represents characteristic frequency associated with irreversible energy dissipation encoded by T.

This transformation preserves energy and frequency while reversing the orientation of helicoidal circulation. Matter and antimatter are therefore topological conjugates of the same underlying field.

8.4 Pair Creation and Chirality Conservation

Topological charge conservation favors pair creation. The minimal creation event consists of a particle–antiparticle pair with opposite chirality:

$$n_{total} = n + (-n) = 0$$

Such pair creation corresponds to the nucleation of two helicoidal solitons with opposite chirality but identical energy scale and frequency, emerging from a single coherent instability.

8.5 Matter–Antimatter Annihilation as Topological Unwinding

When a particle and its antiparticle interact coherently, their opposite helicoidal windings allow mutual phase cancellation. If phase locked is achieved, the combined configuration of their opposite windings allows a continuous deformation into the trivial topology:

$$n + (-n) \rightarrow 0$$

This process corresponds to annihilation, interpreted here as a controlled topological unwinding rather than destruction. The released energy is redistributed into delocalized field modes or radiative helicoidal waves, consistent with observed annihilation phenomenology.

Here CPT symmetry, commonly understood as invariance under charge, parity, and time reversal, is not replaced but reinterpreted as a manifestation of helicoidal conjugation at the topological level. Althought a full account of CPT symmetry lies beyond the scope of the presente framework.

8.6 Conceptual Summary

Particle creation is a nonlocal, coherence-driven instability governed by order parameters and topological invariants. It is therefore a selective, topology-driven process, rather than a generic excitation. Antimatter emerges as the helicoidal conjugate of matter, embedding creation and annihilation within a unified dissipative geometric framework.

Although the present framework does not employ canonical creation and annihilation operators, it remains compatible with QFT at the effective level. Collective coherence modes play a role analogous to vacuum excitations, while solitonic particles correspond to nonperturbative, topologically protected field configurations, similar to vortices or solitons in established quantum field models.

Conservation laws, including energy and charge conjugation, are preserved through global topological constraints. In this sense, standard QFT emerges as an effective description of underlying coherent and dissipative field dynamics, rather than as a fundamental ontology.

9. Three-Dimensional Structure and Solitonic Knots

The present model offers a natural explanation for the emergence of three spatial dimensions. This dimensionality is not assumed a priori, but follows from topological constraints governing the stability, linking, and mutual reinforcement of helicoidal vortices.

No relativistic spacetime structure is assumed in what follows. Neither Minkowski geometry nor Lorentz invariance is taken as fundamental. The present analysis does not operate within a predefined (3+1)-dimensional spacetime, but instead addresses the origin of spatial dimensionality itself as an emergent topological constraint on stable field configurations. Lorentz symmetry, if present, is interpreted as an effective kinematic regularity arising at the level of collective, coarse-grained dynamics rather than as a primitive organizing principle. The argument therefore precedes and underlies any relativistic description.

In two spatial dimensions, vortex structures are necessarily planar and cannot form non-trivial knots or links. All closed trajectories are topologically reducible, and no conserved helicity or linking invariant exists to protect solitonic configurations against continuous deformation. As a consequence, persistent, self-confined material excitations cannot arise in two-dimensional settings.

In spatial dimensions higher than three, linking numbers and helicity lose their confining character. Vortex intersections can be continuously disentangled through higher-dimensional embeddings without topological obstruction, preventing the formation of isolated, stable knots and eliminating any minimal isotropic configuration.

Three spatial dimensions therefore constitute the minimal and unique dimensionality in which helicoidal vortices can simultaneously exhibit non-trivial knotting, conserved helicity, topological protection against unwinding, and isotropic self-confinement without preferred directions. Only under these conditions can persistent solitonic structures arise, providing a topological foundation for stable matter and a fully three-dimensional effective space. This dimensional selection arises independently of any background metric or spacetime postulate, reinforcing the pre-geometric character of the present framework.

9.1 Solitonic Knots and Orthogonal Helicoidal Modes

Within this context, a material particle is represented as a stable solitonic knot formed by the coherent intersection of three mutually orthogonal helicoidal vortices, each associated with a principal axis of circulation. The intersection region constitutes a topologically locked configuration of field flow, in which the mutual reinforcement of helicoidal modes prevents unwinding and decay. The persistence of matter thus arises from the self-consistent stabilization of these intersecting vortices.

Three mutually orthogonal helicoidal components represent the minimal isotropic configuration capable of sustaining a fully three-dimensional, orientation-independent topological defect. Such a structure naturally accommodates intrinsic angular momentum, anisotropic interactions, and orientation-dependent coupling to external fields.

In three spatial dimensions, the helicoidal–solitonic structure is assumed to possess simultaneous phase-winding components projected onto the three fundamental coordinate planes x, y, and z. This configuration corresponds to a fully three-dimensional topological phase defect rather than a single-axis vortex. The isotropic form of the Complex Ginzburg–Landau equation naturally accommodates such multi-planar helicoidal modes.

Formally, the fundamental field is decomposed into three helicoidal components:

$$\Psi(x, \tau) = \Sigma_{i=1}^{3} \Psi_i(x, \tau)$$

Here, the decomposition into three helicoidal components with the index i should be understood as an internal mode expansion. It does not correspond to a sum of independent relativistic spacetime fields.

This is a minimal isotropic solution. But each helicoidal component is not an independent solution. Instead, it is a projected mode of a single nonlinear field, coupled through amplitude saturation and phase locking terms. Each one represents a metastable dissipative mode. True particle-like stability emerges only when the three modes intersect coherently, forming a topological locked composite solution.

Each component is defined as a helicoidal mode aligned with one of the Cartesian axes:

$$\Psi_i(x, \tau) = A_i(r_a) \exp [i(n_i \theta_i + k_i x_i - \omega_i \tau)]$$

with:

$x_a \in \{x, y, z\}$ the longitudinal axis of the vortex;

$r_a = \sqrt{x^2_j + x^2_k}$;

$\theta_i = \tan^{-1} (x_k/x_j)$;

$n_i \in \mathbb{Z}$.

Here r_a denotes the radial coordinate in the plane orthogonal to axis x_a.

While each helicoidal component represents a stable dissipative soliton, matter emerges only when all three modes coexist and intersect coherently, forming a fully three-dimensional, topologically protected solitonic knot.

9.2 Topological Locking and Knot Formation

The intersection of the three vortices defines a solitonic knot, characterized by non-zero mutual linking numbers between the field components. The topological stability of the particle is quantified by the total linking invariant:

$$\mathcal{L} = \Sigma_{i<j} \mathcal{L}_{ij}$$

where the pairwise linking number between two helicoidal components is:

$$\mathcal{L}_{ij} = 1 / 4\pi \oint C_i \oint C_j (x_i - x_j) \cdot (dx_i \times dx_j) / |x_i - x_j|^3$$

Here, x_i and x_j denote the longitudinal coordinate along the helicoidal vortex axes.

The total linking number provides a discrete geometric realization of the Hopf invariant associated with the composite configuration. A non-zero value of $\mathcal{L}$ implies that the helicoidal flows cannot be continuously deformed into an unlinked state without topological rupture. Dissipation may alter amplitudes and local geometry, but cannot eliminate the knot.

9.3 Helicity as a Conserved Topological Charge

The three-dimensional solitonic particle carries a finite field helicity $\hat{H}$, defined as:

$$\hat{H} = \int A \cdot (\nabla \times A) \, d^3x$$

where A corresponds to an effective flow potential associated with the helicoidal phase structure, not fundamental gauge field.

For the composite solitonic knot:

$$\hat{H} \propto \Sigma^{3}_{i=j} n^{2}_{i}\Gamma^{2}_{i} + 2\Sigma_{i<j} n_i n_j \Gamma_i \Gamma_j$$

with Γ_i representing the flux of each helicoidal vortex.

This helicity is approximately conserved under dissipative evolution as long as reconnection events are topologically forbidden, ensuring particle persistence despite energy loss.

9.4 Self-Confinement and Isotropy

A single helicoidal vortex defines a preferred axis and intrinsically anisotropic. The superposition of three mutually orthogonal vortices constitutes the minimal isotropic configuration capable of sustaining a fully three-dimensional, orientation-independent soliton.

The effective confinement potential near the knot core can be approximated as:

$$V_{eff}(\mathbf{r}) \sim \sum_{i=1}^{3} \left| n^{2}_{i} / r_{a}^{2}{}_{i} + \lambda_i |\Psi_i|^4 \right|$$

which admits a stable minimum at the intersection point:

$$\nabla V_{eff} = 0$$

Here V_{eff} represents a conceptual physical approximation and serves a heuristic role. This defines a self-convergent topological center, without invoking external blinding forces.

This potential is not rigorously derived. It represents an effective energetic landscape for heuristic purposes.

9.5 Energy Density and Relational Spatial Gradient

Building upon the three-dimensional solitonic knot model, we introduce an explicit treatment of internal energy density. Each helicoidal vortex is associated with $\rho_i(x)$, representing the local energy density, defined as a function of the radial distance r_a from the vortex axis. For the three mutually orthogonal vortices Ψ_i, the total energy density of the particle is defined as:

$$\rho_{total}(x) = \Sigma_{i=1}^{3} \rho_i(x)$$

The energy functional $\rho_i(x)$ is positive definite and admits a localized maximum at the vortex core. Its spatial profile may be approximated by a Gaussian-like or Lorentzian envelope:

$$\rho_i(x) \approx \rho_{0i} \exp[-(\rho_i / \sigma_i)^2]$$

where:

$\rho_i = \sqrt{(xj^2 + xk^2)}$ is the radial distance from the core along the transverse plane;

σ_i is the characteristic vortex width**;**

ρ_{0i} is the peak energy density.

The densification of the solitonic cores induces a relational spatial gradient. Let R be the effective distance between particle centers emerging from the overlap of energy densities. The gradient of relational space is naturally related to energy density by:

$$\nabla R \approx k \Sigma_{i=1}^{3} \nabla \rho_i(x)$$

where k is a proportionality constant encoding the sensitivity of relational separation to internal energy compression. Both ∇R e k are physical approximations. They establish a direct connection between local energetic densification and emergent spatial separation, consistent with the conceptual framework of relational distance derived from helicoidal dissipation.

The energy density $\rho_{total}(x)$ thus provides both a measure of internal confinement and a source of effective spatial ordering, reinforcing the three-dimensional stability of the solitonic knot.

9.6 Spin and Intrinsic Angular Momentum

The intrinsic angular momentum of the particle arises from the circulation of helicoidal flows, rather than from rigid-body rotation. The total spin vector S is given by:

$$S = \int r \times p_{field}\, d^3x$$

with the field momentum density:

$$p_{field} \propto \mathrm{Im}(\Psi^* \nabla \Psi)$$

derived from the local helicoidal flow of Ψ.

Im(...) indicates the imaginary part of a complex expression, here extracting the real momentum contribution from $\Psi^* \nabla\Psi$.

For the three-vortex knot, this yields a quantized spin magnitude proportional to the sum of winding numbers:

$$|S| \propto \sum_{i=1}^{3} n_i$$

establishing a natural topological origin for intrinsic angular momentum.

The total spin vector magnitude scales with the net topological circulation, while the spin vector orientation is determined by the relative phase locking of the three helicoidal components.

9.7 Fermionic Solitons and Half-twist Framing

In addition to integer phase winding, a three-dimensional solitonic knot may carry an internal half-twist associated with the transverse

structure of each helicoidal flux tube. Each tube is treated as a framed structure, characterized by an internal twist parameter τ_i.

While the global winding and linking numbers remains integer-valued, the internal twist of the flux tube may assume half-integer values, implying that the field configuration returns to itself only after a 4π rotation. This structure provides a natural topological origin for spin-1/2 behavior without invoking fundamental spinor fields.

The intrinsic angular momentum of the solitonic knot is therefore determined not only by integer helicoidal windings n_i, but also by the presence of half-twist framings τ_i, yielding:

$$S \propto \sum_{i=1}^{3} ❑ (n_i + ½\ \tau_i)$$

where:

$n_i \in \mathbb{Z}$ is the helicoidal winding;

$\tau_i \in 0,1$ is half-twist in the flux tube.

Thus we have:

$\tau = 0$ is integer spin;

$\tau = 1$ is half-integer spin.

This construction reproduces the defining property of fermions: invariance of all physical observables under 4π rotation, while allowing a sign change of the internal phase structure under 2π rotation.

Importantly, no fundamental spinor fields or quantization postulates are introduced. Spinorial behavior emerges purely from the topological framing or the helicoidal field. Such configurations are topologically equivalent to dynamic Möbius-type framing in phase space and provide a natural geometric realization of spinorial behavior.

Each helicoidal component is therefore not only a phase line but a framed tube of field flow, characterized by a local transverse orientation. The topological structure of such a framed vortex is described by the classical decomposition:

$$Lk = Wr + Tw$$

where:

Lk is the linking number;

Wr is the writhe;

Tw is the twist.

This is a classical formulation of Călugăreanu-White-Fuller. Tw may assume half-integer values, even when Lk is an integer. A half-twist configuration corresponds to the situation in which the transverse field orientation reverses after a 2π rotation, returning to itself only after a 4π rotation.

Here the signal is not directly observable, but influences exchange and transfer.

The half-twist framing is protected by topological constraints and remain invariant under dissipative evolution. The Global Phase Correction acts only on integer phase mismatches and does not eliminate half-twist structures, thereby preserving fermionic identity throughout irreversible dynamics.

Fermions and bosons thus arise as distinct topological classes of helicoidal solitonic knots within a unified dissipative field framework. Spin, statistics, and rotational behavior are reinterpreted as manifestations of geometric and topological properties of persistent field configurations, rather than as fundamental algebraic atributes imposed a priori.

9.8 Orientation-Dependent Couplings

External fields couple to the solitonic knot through phase and amplitude perturbations of individual helicoidal components. The interaction Hamiltonian takes the anisotropic form:

$$H_{int} = \sum_{i=1}^{3} \gamma_i E \cdot \hat{e}_i |\Psi|^2$$

Where E is the external field and $\hat{e}_i$ is the unit vector along the axis of each helicoidal vortex.

This naturally explains directional coupling, polarization sensitivity, and anisotropic response, without postulating intrinsic point-like charges. Also, the equation does not evoke fundamental electromagnetism, but phase-amplitude coupling.

9.9 Exchange, Statistics and Topological Phase

The distincion between bosonic and fermionic statistics emerges naturally in the present framework from topological properties of solitonic knots under exchange operations. Particle exchange is not treated as an abstract permutation of labels, but as a continuous deformation of two extended topological configurations within the helicoidal field.

Consider two identical solitonic knots initially separated in space. An exchange process corresponds to a continuous braiding of their world-tubes in configuration space. The resulting configuration acquires a geometric phase determined by the topology of the braid and by internal framing of the solitonic structures.

For bosonic solitons, characterized by integer helicoidal winding an trivial internal framing ($\tau_i = 0$), the exchange braid is topologically equivalent to the identity. The associated geometric phase is:

$$\Delta\Phi_{ex} = 0 \ (\text{mod } 2\pi)$$

For fermionic solitons carryng one or more half-twist framings ($\tau_i = 1$), the exchange braid is topologically non-trivial. The half-twist framing induces an additional π phase shift under a single exchange, yielding:

$$\Delta\Phi_{ex} = \pi \pmod{2\pi}$$

This phase does not arise from algebraic anticommutaion relations, but from the geometric holonomy associated with transporting a framed solitonic knot around another in configuration space. The exchange statistics are therefore determined by the topological class of the soliton rather than by imposed operator rules.

The Global Phase Correction preserves this exchange-induced topological phase by stabilizing the half-twist framing during collective evolution. While local phase mismatches are corrected through dissipative dynamics, the global braid topology remains invariant, ensuring the persistence of fermionic or bosonic identity under interaction exchange.

In this model, Bose-Einstein and Fermi-Dirac statistics emerge as macroscopic manifestations of distinct topological exchange classes of helicoidal solitonic knots. Quantum statistics are thus reinterpreted as consequences of field geometry and topology, rather than as fundamental axioms of the theory.

This framework naturally accomodates the spin-statistics connection: solitons with half-twist framing exhibit both half-integer spin and antisymmetric exchange behavior, while solitons without internal twist exhibit integer spin and symmetric exchange. The spin-statistics theorem is therefore recovered as a topological correlation within the helicoidal field dynamics, without invoking relativistic quantum field postulates.

Also, while Skyrme-type models stabilize particles through energetic terms in a conservative field theory, the solitonic particle constructed here is a dissipative framed Hopf-Skyrme composite. It is a non-trivial element of $\pi_3(S^2)$ whose stability, spin and exchange statistics arise

from helicity, linking and twist invariants rather than from imposed Langragian constraints.

9.10 Conceptual Closure

A material particle is thus identified with a three-dimensional solitonic knot, stabilized by conserved helicity, non-zero linking numbers and mutual reinforcement of orthogonal helicoidal flows.

Matter is made not of static objects, but of persistent topological processes, a self-locked configuration of field motion embedded in a dissipative medium.

10. Discussion and Outlook

The Helicoidal–Solitonic Field Model proposes a unified conceptual framework in which particle identity, dissipation, irreversibility, particle creation, and the emergence of space arise from a single underlying field dynamics. Matter, interaction, and spacetime are not introduced as independent primitives, but are interpreted as collective manifestations of helicoidal field organization and its irreversible evolution.

Although the present work is primarily conceptual, it establishes a coherent physical picture that may serve as a foundation for future mathematical formalization and phenomenological investigation. Its close connections with nonlinear field theory, vortex dynamics, and topological solitons suggest multiple directions for analytical development and experimental analogy.

Within this framework, space, time, and interaction are emergent rather than fundamental.

Space arises from cumulative helicoidal dissipation. The progressive contraction of solitonic configurations, driven by irreversible phase loss, generates effective relational separation between particle centers. Spatial distance is therefore a derived relational quantity, not a pre-existing geometric substrate. Spacetime geometry functions as a memory of past dissipative processes rather than as an independente background.

Interactions emerge from phase couplings between helicoidal structures. Constructive and destructive interference among coherent phases give rise to effective attractive and repulsive forces, without the need for mediating particles or independent force carriers.

Gravitation, in particular, appears as a universal statistical attraction associated with collective phase coherence and irreversible dissipation, consistent with emergent gravity paradigms.

Time corresponds to helicoidal irreversibility. The intrinsic directionality of topological evolution, encoded in phase slippage and dissipative processes, provides a physical basis for temporal ordering and for the arrow of time, rather than treating time as an external parameter.

This relational interpretation naturally accommodates cosmological observations such as redshift and inferred expansion, without requiring the literal stretching of a pre-existing spatial container. Apparent expansion arises instead from phase evolution and cumulative relational separation generated by helicoidal dynamics.

Matter, in this view, is not a static substance but a self-convergent mode of field motion, stabilized by topology and sustained through controlled dissipation.

Particles are not fundamental objects but long-lived topological processes.

Mass corresponds to the degree of internal energetic confinement within a helicoidal solitonic structure, while gravitational interaction

represents an externalized energetic residue associated with irreversible internal dissipation.

Massless radiation corresponds to an open-phase dynamical regime in which helicoidal self-confinement is dynamically forbidden. In this regime, coherence and propagation are preserved, but localized solitonic cores cannot form, preventing the emergence of rest mass.

Finally, the Retro-Expansion hypothesis, according to which the Universe originates from a single original particle undergoing progressive densification, fragmentation, and phase differentiation, is naturally compatible with the Helicoidal–solitonic Field Model. The primordial particle may be interpreted as a maximally confined solitonic state, while subsequent particle formation, radiation, gravitation, and effective spatial separation arise as phase-dependent consequences of incomplete self-confinement.

11. Phenomenological Signatures and Testable Predictions

Although the present model is primarily conceptual, it implies a set of minimal and testable predictions that distinguish it from point-particle and strictly conservative field descriptions. While the present framework is not yet predictive in a quantitative sense, is not metaphysical. It implies concrete phenomenological distinctions that in principle allow experimental discrimination.

11.1 Intrinsic Dissipation with Topological Stability

Prediction: fundamental particles should exhibit irreversible microscopic behavior associated with internal degrees of freedom, while preserving their identity over arbitrarily long timescales.

Implication: there exists a form of internal energy redistribution or phase hysteresis that is not captured by purely unitary evolution but does not lead to particle decay.
Possible observational windows: deviations from perfectly reversible dynamics in high-precision interferometric or coherence-based experiments; anomalous phase noise floors not attributable to environmental decoherence alone.
This contrasts with standard models, where irreversibility arises only from external interactions or coarse-graining.

11.2 Mass–Time Drift via Secular Core Compression

Prediction: if solitonic cores undergo progressive topological contraction, particle properties associated with internal phase density (e.g., effective mass or inertial response) may exhibit extremely slow secular drift over cosmological timescales.
Implication: fundamental “constants” related to particle structure may not be strictly constant, but evolve monotonically at rates far below current laboratory sensitivity.

Possible observational windows: high-redshift spectroscopic comparisons of atomic transition lines; long-baseline cosmological constraints on mass ratios or coupling constants.

This provides an alternative microphysical interpretation for apparent constancy with allowable ultra-slow evolution.

11.3 Emergent Expansion Without Metric Stretching

Prediction: observed cosmological redshift can arise from relational distancing between matter structures rather than from expansion of an underlying metric.

Implication: the effective expansion rate depends on matter distribution and solitonic evolution, not solely on spacetime geometry.

Possible observational windows: subtle correlations between redshift behavior and matter density environments; deviations from strict homogeneity in expansion inferred from relational measurements.

This differs from standard cosmology, where expansion is purely geometric and independent of matter microstructure.

11.4 Collective Resonant Particle Creation

Prediction: particle creation is favored in regimes of global or mesoscopic phase coherence, rather than being strictly local and stochastic.

Implication: high-energy environments with coherent field modes should display non-Poissonian creation statistics.

Possible observational windows: correlated particle production in high-energy collisions; enhanced pair creation rates in structured electromagnetic or plasma fields.
This predicts subtle departures from random, uncorrelated creation events.

11.5 Directional and Topological Interaction Anisotropies

Prediction: if particles are composed of intersecting helicoidal vortices, their interactions may depend weakly on relative orientation and topological alignment.

Implication: scattering amplitudes could contain small anisotropic components beyond those expected from spin alone.

Possible observational windows: precision angular scattering experiments; orientation-dependent cross-section anomalies not reducible to known symmetries.

11.6 Absence of True Pointlike Singularities

Prediction: no physical particle should behave as a true mathematical point at arbitrarily small scales.

Implication: effective form factors or internal structure signatures should persist, even if extremely suppressed.

Possible observational windows: high-momentum transfer scattering showing deviations from pointlike behavior; energy-dependent effective radii emerging at extreme scales.

11.7 Experimental Discriminants and Limits

The model can be falsified if: all particle dynamics are shown to be strictly unitary and perfectly reversible at all scales; no relational or environment-dependent contribution to cosmological redshift is ever observed; particle creation is demonstrated to be purely local and strictly uncorrelated under all coherent conditions; absolute pointlike behavior persists without deviation at arbitrarily high energies.

If future experimental evidence were to establish that all microscopic dynamics are strictly unitary with no measurable internal hysteresis under any conditions, this would pose a serious challenge to the assumptions underlying the present framework.

Author’s Note on Scope

The predictions advanced in this work are intentionally minimal and conservative. They do not invoke exotic new particles, extra spatial dimensions, or violations of established conservation laws. Instead, the framework explores the possibility that topology, dissipation, and collective dynamics play a more fundamental role in physical organization than is typically assumed.

This work was developed through independent conceptual exploration over several years. Language refinement and editorial assistance were used only in the preparation of the manuscript.

The present work is intended as a conceptual and programmatic exploration, rather than as a complete microscopic theory of fundamental interactions. The helicoidal–solitonic field model is formulated at an effective and phenomenological level, with the primary objective of investigating how particle identity, microscopic irreversibility, and aspects of spacetime structure might emerge from dissipative and topological field dynamics.

At its current stage, the framework does not aim to reproduce the full quantitative structure of the Standard Model, including precise mass spectra, coupling constants, or renormalization-group behavior. Instead, it seeks to offer a coherent ontological and dynamical picture in which long-term particle stability, intrinsic irreversibility, and emergent geometric notions arise from a single underlying mechanism.

Similarly, the discussion of emergent spatial structure and effective attractive interactions is not intended as a derivation of general relativity, nor as a direct modification of gravitational theory. The inverse-distance behavior obtained should be interpreted as a large-scale phenomenological consequence of collective phase dynamics and dissipation, whose precise quantitative correspondence with known gravitational phenomena remains an open question.

Several elements of the framework, including collective synchronization effects, global phase-regulation mechanisms, and the long-term secular evolution of solitonic cores, are introduced as working hypotheses, motivated by internal consistency and by analogies with known dissipative systems. Their detailed mathematical formulation and experimental relevance are left for future investigation.

In this sense, the present model should be viewed as a research program. It proposes a coherent conceptual structure, identifies key mechanisms, and outlines potential phenomenological consequences, while deliberately remaining open to refinement, falsification, or partial replacement as further theoretical and experimental insights become available.